

DESCRIPTION

HIGHLY CORROSION-RESISTANT HOT DIP PLATED STEEL MATERIAL
EXCELLENT IN SURFACE SMOOTHNESS

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Technical Field

The present invention relates to a plated steel sheet and, more specifically, to a steel material having an excellent surface smoothness and being applicable to various applications such as steel sheets for home electric appliances, automobiles and building materials.

Background Art

Among plated steel materials most commonly used as having a good corrosion resistance, there are galvanized-type and aluminum-plated-type steel sheets. Such plated steel sheets are used in various manufacturing industries including the fields of automobiles, home electric appliances and building materials. In addition to those, plated steel materials are used in various fields including plated steel wires and hot dip plating. In particular, steel materials to which Al-added plating is applied have a high corrosion resistance and, therefore, have been increasingly used in recent years.

The present inventors, with the aim of improving the corrosion resistance of such galvanized-type steel sheets, have proposed Zn-Al-Mg-Si hot dip plated steel sheets in Japanese Patent No. 3179446. Further, the present inventors have clarified, in Japanese Unexamined Patent Publication No. 2000-064061, the fact that a painted steel sheet more excellent in corrosion resistance can be obtained by adding one or more elements of Ca, Be, Ti, Cu, Ni, Co, Cr and Mn to such a proposed Zn-Al-Mg-Si hot dip plated steel sheet.

Further, it is disclosed in Japanese Unexamined Patent Publication No. H5-125515 that, when Ti is added to a Zn-Al hot dip plated steel sheet with the aim of

improving the corrosion resistance of a galvanized-type steel sheet, the steel sheet is excellent in resistance to black discoloration with age. Furthermore, it is disclosed in Japanese Unexamined Patent Publication No. 2001-295015 that a surface appearance is improved by adding Ti, B and Si to a Zn-Al-Mg hot dip plated steel sheet.

However, with the aforementioned and with other disclosed plated steel sheets, surface smoothness is insufficiently secured.

In the case of a Zn-Al binary alloy, the eutectic point thereof is 6%Al-94%Zn in mass and, when an Al concentration is higher than that, an Al phase crystallizes as a primary crystal. Meanwhile, in the case of an Al-Si binary alloy, the eutectic point thereof is 87.4%Al-12.6%Si in mass and, when an Al concentration is higher than that, an Al phase crystallizes as a primary crystal.

In the case of a Zn-Mg-Al ternary alloy, the ternary eutectic point thereof is 3%Mg-4%Al-93%Zn in mass and when an Al concentration is higher than this an Al phase crystallizes as a primary crystal. When a solidification speed of plating is sufficiently secured at the time of hot dip plating, the plating solidifies before an Al phase grows large and therefore surface smoothness does not deteriorate. In contrast, when a solidification speed of plating is low, the problem is that an Al phase grows large at first, causing ruggedness to form on a plated surface and, as a result, the surface smoothness deteriorates.

Nevertheless, the technology disclosed in the aforementioned Japanese Patent No. 3179446 does not take the problem of the deterioration of surface smoothness into consideration. Further, though the technology disclosed in the aforementioned Japanese Unexamined Patent Publication No. 2000-064061 employs the addition of one or more elements of Ca, Be, Ti, Cu, Ni, Co, Cr and

Mn with the aim of improving post-painting corrosion resistance, the technology neither takes the problem of the deterioration of surface smoothness into consideration nor refers to an intermetallic compound.

5 The technology disclosed in the aforementioned Japanese Unexamined Patent Publication No. H5-125515 does not take the problem of the deterioration of surface smoothness into consideration. Furthermore, though the technology disclosed in the aforementioned Japanese Unexamined
10 Patent Publication No. 2001-295015 employs the addition of Ti and B with the aim of suppressing the formation and growth of a $Zn_{11}Mg_2$ phase that deteriorates surface appearance, the technology neither takes the problem of the deterioration of surface smoothness into
15 consideration nor refers to an intermetallic compound.

Disclosure of the Invention

The present invention has been addressed in the light of the above problems and the object thereof is to
20 provide a plated steel material excellent in surface smoothness even in the case of a high Al concentration exceeding 4% in mass.

The present invention has been established to solve the above problems and the gist thereof is as follows;

25 (1) A highly corrosion-resistant hot dip plated steel material excellent in surface smoothness, characterized by having on the surface thereof a plated layer which contains Al of 4% or more in mass and has an Al-type intermetallic compound in an Al phase.

30 (2) A highly corrosion-resistant hot dip plated steel material excellent in surface smoothness, characterized by having on the surface thereof a plated layer which contains Al of 4% or more in mass and has an Al-type intermetallic compound abutting on an Al phase.

35 (3) A highly corrosion-resistant hot dip plated steel material excellent in surface smoothness according to the item (1) or (2), characterized in that said plated

layer contains Al of 4 to 20% and Mg of 1 to 10% in mass with the balance consisting of Zn and unavoidable impurities.

5 (4) A highly corrosion-resistant hot dip plated steel material excellent in surface smoothness according to the item (1) or (2), characterized in that said plated layer contains Al of 4 to 20%, Mg of 1 to 10% and Si of 0.001 to 2% in mass with the balance consisting of Zn and unavoidable impurities.

10 (5) A highly corrosion-resistant hot dip plated steel material excellent in surface smoothness according to any one of the items (1) to (4), characterized by having on the surface thereof a plated layer containing an intermetallic compound having a melting point of 600°C or higher by 0.001 to 0.5% in mass.

15 (6) A highly corrosion-resistant hot dip plated steel material excellent in surface smoothness, characterized in that at least one of the lattice constants of said intermetallic compound according to any one of the items (1) to (5) is in the range from 3 to 5 Å.

20 (7) A highly corrosion-resistant hot dip plated steel material excellent in surface smoothness, characterized in that said intermetallic compound according to any one of the items (1) to (6) is one or more of an Ni-Al-type intermetallic compound, a Ti-Al-type intermetallic compound, a Zr-Al-type intermetallic compound and an Sr-Al-type intermetallic compound.

25 (8) A highly corrosion-resistant hot dip plated steel material excellent in surface smoothness, characterized in that said intermetallic compound according to any one of the items (1) to (7) is one or more of TiAl_3 , NiAl_3 , Co_2Al_9 , $\text{Co}_4\text{Al}_{13}$, CrAl_4 , CrAl_7 , $\text{Cr}_2\text{Al}_{11}$, $\text{Mn}_4\text{Al}_{11}$, MnAl_6 , $\text{Al}_{11}\text{Ce}_3$, CeZn_2Al_2 , Al_9Ir_2 , $\text{Al}_{11}\text{La}_3$, Al_{12}Mo , NbAl_3 , Al_2Se_3 , TaAl_3 , ZrAl_3 , Zr_2ZnAl_3 , Al_2Ca , $\text{Ti}_7\text{Al}_6\text{Si}_{12}$, FeNiAl_9 , $\text{Fe}_3\text{NiAl}_{10}$, TiAl_2 , TiAl , Ni_2Al_3 , NiAl and SrAl_4 .

30 (9) A highly corrosion-resistant hot dip plated

steel material excellent in surface smoothness,
characterized in that said Ti-Al-type intermetallic
compound according to the item (7) is $\text{Ti}(\text{Al}_{1-x}\text{Si}_x)_3$.

5 Brief Description of the Drawings

Figure 1 consists of views showing an example of an
intermetallic compound existing in an Al phase: Figure
1(a) is a microphotograph (magnification: 3,500) of the
plated layer of a plated steel material; and Figure 1(b)
10 is an illustration showing the distribution state of each
structure in the microphotograph of the plated layer of
the plated steel material.

Figure 2 consists of views showing an example of the
solidification structure of a plated layer: Figure 2(a)
15 is a microphotograph (magnification: 2,500) of the plated
layer of a plated steel material according to the present
invention; and Figure 2(b) is an illustration showing the
distribution state of each structure in the
microphotograph of the plated layer of the plated steel
20 material according to the present invention.

Best Mode for Carrying Out the Invention

The present invention is explained in detail
hereunder.

25 The hot dip plated steel materials according to the
present invention include: a plated steel material
characterized by having on the surface thereof a plated
layer which contains Al of 4% or more in mass and has an
Al-type intermetallic compound in an Al phase; and a
30 plated steel material characterized by having on the
surface thereof a plated layer which contains Al of 4% or
more in mass and has an Al-type intermetallic compound
abutting on an Al phase.

In the present invention, hot dip plating means
35 plating which uses metal prepared: by adding Al and, if
necessary, further one or both of Si and Mg to a molten
Zn bath; or by adding Si and, if necessary, further one

or both of Zn and Mg to a molten Al bath.

In a plating bath, besides the above components, Fe, Sb, Pb, Sn and unavoidable impurities may be contained individually or in combination by 0.5% or less in mass.

5 Further, even when Ca, Be, Cu, Co, Mn, P, B, Bi and the third group elements are contained by 0.5% or less in mass in total, the effect of the present invention is not hindered and rather, in some favorable cases, corrosion resistance is further improved depending on the addition
10 amount.

The reason why an Al content is limited to 4% or more in mass in the present invention is that, if an Al content is less than 4% in mass, the effect of improving corrosion resistance is insufficient. Meanwhile, when an
15 Al content is less than 4% in mass, an Al phase does not crystallize as a primary crystal and therefore the problem of the deterioration of smoothness does not arises. The upper limit of an Al content is not particularly regulated. However, it is desirable that an
20 Al content is 95% or less in mass in order to avoid too high a plating bath temperature.

In the present invention, an Al phase is the phase that looks like an island or a dendrite having a clear boundary in a plated layer and the phase corresponds to,
25 for example, an "Al phase" (an Al solid solution that contains Zn in the state of a solid solution) at a high temperature in an Al-Zn binary phase equilibrium diagram. In such an Al phase at a high temperature, the amount of dissolved Zn varies in accordance with the concentration
30 of Al in a plating bath. An Al phase at a high temperature usually separates into a fine Al phase and a fine Zn phase at an ordinary temperature and it is reasonably estimated that the island shape observed at an ordinary temperature is the residue of the Al phase at a
35 high temperature. The phase that derives from such an Al phase (called an Al primary crystal) at a high temperature and retains the shape of the Al phase is

called an Al phase in the present invention.

5 In the case of an Al phase of an Al-Si binary, Al-Zn-Si ternary, Al-Zn-Mg ternary, Al-Mg-Si ternary or Al-Zn-Mg-Si quaternary alloy, the amount of dissolved
elements and also the shape of the phase at an ordinary
temperature vary in accordance with the variation of the
concentration in the alloy in a plating bath. However,
in any of the cases, the Al phase retains the shape
derived from an Al primary crystal, is clearly identified
10 under microscopic observation and thus is called an Al
phase in the present invention.

Here, plating of a poor surface smoothness
represents a state wherein ruggedness is formed on the
surface of a plated layer at the intervals of several
15 tens micrometers to several millimeters and can
sufficiently be observed visually. When the cross
section of a plated layer is observed with an optical
microscope, the plated layer is classified into the
portions of thick plated layers and thin plated layers
and, in some extreme cases, the thickness of a thin
20 portion is less than half that of a thick portion. The
smoothness can be evaluated by measuring the roughness in
the wavelength range of 50 μm or more.

The reason why the position of an Al-type
25 intermetallic compound in a plating layer is limited to a
position in an Al phase or a position abutting on an Al
phase in the present invention is that, with an
intermetallic compound existing at a position other than
the above, surface smoothness cannot be improved.

30 The reason why an Al-type intermetallic compound
existing in an Al phase or abutting on an Al phase
improves surface smoothness is presumably that the
inoculation effect, that an Al-type intermetallic
compound provides, acts as the crystallization nucleus of
35 an Al phase causes many Al phases to crystallize even at
a low cooling rate and the solidification of a plated
layer to become uniform.

As a result of the present inventors' investigation of Al phases in many plated layers, intermetallic compounds several micrometers in size were observed in most of the Al phases or at portions abutting on the Al phases. An example of an intermetallic compound existing in an Al phase is shown in Figure 1. Figure 1(a), the upper half of Figure 1, is a microphotograph (magnification: 3,500) of the plated layer of a plated steel material according to the present invention and Figure 1(b), the lower half thereof, is an illustration showing the distribution state of each structure in the microphotograph. As can be understood from the figures, each structure can clearly be identified by a microphotograph of the plated layer of a plated steel material according to the present invention.

The size of an intermetallic compound is not particularly limited in the present invention. Incidentally, the sizes of the intermetallic compounds observed by the present inventors were 10 μm or smaller. The percentage of Al phases wherein intermetallic compounds exist is not particularly limited either. However, it is desirable that the rate of Al phases wherein intermetallic compounds exist exceeds 10% of all Al phases.

Plated steel materials having a highly corrosion-resistant particularly in various environments among those according to the present invention include a plated steel material characterized by having on the surface thereof a plated layer containing Al of 4 to 20% and Mg of 1 to 10% in mass with the balance consisting of Zn and unavoidable impurities or a plated layer containing Al of 4 to 20%, Mg of 1 to 10% and Si of 0.001 to 2% in mass with the balance consisting of Zn and unavoidable impurities.

The reasons why an Al content is limited to 4 to 20% in mass are that, if it is less than 4% in mass, the effect of improving corrosion resistance is insufficient,

that, within that range, the problem of the deterioration of smoothness caused by the lack of the crystallization of an Al phase as a primary crystal is avoided, and that, if it exceeds 20% in mass, the effect of improving corrosion resistance is saturated.

The reason why an Mg content is limited to 1 to 10% in mass is that, if it is less than 1% in mass, the effect of improving corrosion resistance is insufficient and, if it exceeds 10% in mass, a plated layer embrittles and thus adhesiveness deteriorates.

Si has the effect of suppressing the growth of an Fe-Al alloy layer and improving plating adhesiveness. For that reason, it is effective to add Si when an Fe-Al alloy layer is likely to grow as in the case of a high plating bath temperature or a large Al content. The reason why an Si content is limited to 0.001 to 2% in mass is that, if it is less than 0.001% in mass, the effect of suppressing the growth of an Fe-Al alloy layer in a plated layer is insufficient and, if it exceeds 2% in mass, the effect of improving adhesiveness is saturated.

In the present invention, a Zn-Mg-Al-type plated layer forms a metallographic structure containing one or more of a [Zn phase], an [Al phase] and a [Zn₂Mg phase] in the substrate of an [Al/Zn/Zn₂Mg ternary eutectic structure]. Then, a Zn-Mg-Al-Si-type plated layer forms a metallographic structure containing one or more of a [Zn phase], an [Al phase], a [Zn₂Mg phase], an [Si phase] and an [Mg₂Si phase] in the substrate of an [Al/Zn/Zn₂Mg ternary eutectic structure].

Here, an [Al/Zn/Zn₂Mg ternary eutectic structure] is the ternary eutectic structure comprising an Al phase, a Zn phase and an intermetallic compound Zn₂Mg phase. The Al phase which composes the ternary eutectic structure corresponds to, for example, an [Al" phase] (an Al solid solution that contains Zn in the state of a solid solution and includes a small amount of Mg) at a high

temperature in an Al-Zn-Mg ternary phase equilibrium diagram. Such an Al" phase at a high temperature usually appears in the state of separating into a fine Al phase and a fine Zn phase at an ordinary temperature. Further,
5 the Zn phase in the ternary eutectic structure contains a small amount of Al in the state of a solid solution and, in some cases, is a Zn solid solution wherein a small amount of Mg is dissolved further. The Zn₂Mg phase in the ternary eutectic structure is an intermetallic
10 compound phase existing in the vicinity of the point indicated at about 84% in mass of Zn in the Zn-Mg binary phase equilibrium diagram. As long as it is observed in the phase diagram, it is estimated that Si does not dissolve in each phase or, even if it dissolves, the
15 dissolved amount is very small. However, since the very small dissolved amount cannot clearly be identified with an ordinary analysis, the ternary eutectic structure composed of the three phases is expressed by the term [Al/Zn/Zn₂Mg ternary eutectic structure] in the present
20 invention.

Further, an [Al phase] is the phase that looks like an island having a clear boundary in the substrate of the aforementioned ternary eutectic structure and the phase corresponds to, for example, an [Al" phase] (an Al solid
25 solution that contains Zn in the state of a solid solution and includes a small amount of Mg) at a high temperature in an Al-Zn-Mg ternary phase equilibrium diagram. In an Al" phase at a high temperature, the amounts of dissolved Zn and Mg vary in accordance with the concentrations of Al and Mg in a plating bath. Such
30 an Al" phase at a high temperature usually separates into a fine Al phase and a fine Zn phase at an ordinary temperature and it is reasonably estimated that the island shape observed at an ordinary temperature is the residue of the Al" phase at a high temperature. As long
35 as it is observed in the phase diagram, it is estimated that Si does not dissolve in the phase or, even if it

dissolves, the dissolved amount is very small. However, as the very small dissolved amount cannot clearly be identified with an ordinary analysis, the phase that derives from the Al" phase (called an Al primary crystal) at a high temperature and retains the shape of the Al" phase is called an [Al phase] in the present invention. In this case, the [Al phase] can clearly be distinguished from the Al phase composing the aforementioned ternary eutectic structure under microscopic observation.

Furthermore, a [Zn phase] is the phase that looks like an island having a clear boundary in the substrate of the aforementioned ternary eutectic structure and, in some actual cases, a small amount of Al and further a small amount of Mg may dissolve in the phase. As long as it is observed in the phase diagram, it is estimated that Si does not dissolve in the phase or, even if it dissolves, the dissolved amount is very small. In this case, the [Zn phase] can clearly be distinguished from the Zn phase composing the aforementioned ternary eutectic structure under microscopic observation.

Yet further, a [Zn₂Mg phase] is the phase that looks like an island having a clear boundary in the substrate of the aforementioned ternary eutectic structure and, in some actual cases, a small amount of Al may dissolve in the phase. As long as it is observed in the phase diagram, it is estimated that Si does not dissolve in the phase or, even if it dissolves, the dissolved amount is very small. In this case, the [Zn₂Mg phase] can clearly be distinguished from the Zn₂Mg phase composing the aforementioned ternary eutectic structure under microscopic observation.

Yet further, an [Si phase] is the phase that looks like an island having a clear boundary in the solidification structure of a plated layer, for example, the phase that corresponds to primary crystal Si in a Zn-Si binary phase equilibrium diagram. In some actual cases, a small amount of Al may dissolve in the phase and

thus, as long as it is observed in the phase diagram, it is estimated that Zn and Mg do not dissolve or, even if they dissolve, their dissolved amounts are very small. In this case, the [Si phase] can clearly be identified in the plated layer under microscopic observation.

Yet further, an [Mg₂Si phase] is the phase that looks like an island having a clear boundary in the solidification structure of a plated layer, for example, the phase that corresponds to primary crystal Mg₂Si in an Al-Mg-Si ternary phase equilibrium diagram. As long as it is observed in the phase diagram, it is estimated that Zn and Al do not dissolve or, even if they dissolve, their dissolved amounts are very small. In this case, the [Mg₂Si phase] can clearly be identified in the plated layer under microscopic observation.

An example of the solidification structure of the aforementioned plated layer is shown in Figure 2. Figure 2(a), the upper half of Figure 2, is a microphotograph (magnification: 2,500) of the plated layer of a plated steel material according to the present invention and Figure 2(b), the lower half thereof, is an illustration showing the distribution state of each structure in the microphotograph. As it can be understood from the figures, each structure can clearly be identified by a microphotograph of the plated layer of a plated steel material according to the present invention.

In the present invention, it is desirable that the melting point of an intermetallic compound contained in a plated layer is 600°C or higher. The reason why surface smoothness improves by containing an intermetallic compound having a melting point of 600°C or higher is presumably that an intermetallic compound of a high melting point acts as a nucleus of a crystal, [Al phase] crystals crystallize in quantity and, as a result the growth of [Al phase] crystals is suppressed.

The reason why the content of an intermetallic compound having a melting point of 600°C or higher is

limited to 0.001 to 0.5% in mass is that, if it is less than 0.001% in mass, the effect of improving surface smoothness is insufficient and, if it exceeds 0.5% in mass, an intermetallic compound concentrates on the surface of a plated layer and poor appearance occurs.

A method of adding an intermetallic compound is not particularly regulated and a method of mixing fine powder of an intermetallic compound in a bath, a method of melting an intermetallic compound in a bath or the like may be applied. In particular, a bath prepared by melting very small amounts of Ti, Ni, Co, Cr, Mn, Ce, Ir, La, Mo, Nb, Se, Ta, Zr, Ca, Sr, etc. in a Zn-Al alloy liquid at a temperature of 400°C to 600°C and adding the elements which crystallize as an intermetallic compound during solidification before an Al phase crystallizes is very effective in improving surface smoothness.

In the case of a plated layer formed by hot dip plating in a bath to which elements having aforementioned features are added, intermetallic compounds composed of one or more of TiAl_3 , NiAl_3 , Co_2Al_9 , $\text{Co}_4\text{Al}_{13}$, CrAl_4 , CrAl_7 , $\text{Cr}_2\text{Al}_{11}$, $\text{Mn}_4\text{Al}_{11}$, MnAl_6 , $\text{Al}_{11}\text{Ce}_3$, CeZn_2Al_2 , Al_9Ir_2 , $\text{Al}_{11}\text{La}_3$, Al_{12}Mo , NbAl_3 , Al_2Se_3 , TaAl_3 , ZrAl_3 , Zr_2ZnAl_3 , Al_2Ca , $\text{Ti}_7\text{Al}_5\text{Si}_{12}$, FeNiAl_9 , $\text{Fe}_3\text{NiAl}_{10}$, TiAl_2 , TiAl , Ni_2Al_3 , NiAl and SrAl_4 are contained in or beside an Al phase.

Such intermetallic compounds also look like islands having clear boundaries in the solidification structure of a plated layer. When an intermetallic compound is crystallized from an Si added bath, sometimes a small amount of Si may dissolve in the intermetallic compound or a part of Al contained in the intermetallic compound may be replaced with Si.

In the case of an intermetallic compound having a lattice constant close to 4.05 Å, which is the lattice constant of Al in particular, an inoculation effect is likely to be obtained and, for that reason, it is desirable that at least one of the lattice constants of intermetallic compounds is in the range from 3 to 5 Å.

As Al-type intermetallic compounds having the
aforementioned features, an Ni-Al-type intermetallic
compound, a Ti-Al-type intermetallic compound, a Zr-Al-
type intermetallic compound, an Sr-Al-type intermetallic
5 compound and the like, concretely NiAl_3 , TiAl_3 , $\text{Ti}(\text{Al}_{1-x}\text{Si}_x)_3$, ZrAl_3 , SrAl_4 , etc., can be used.

As substrate steel materials in the present
invention, not only steel sheets but also various steel
materials including wire rods, shapes, sections, steel
10 pipes, etc. can be used. As steel sheets, both hot-
rolled and cold-rolled steel sheets can be used and, with
regard to steel types too, various types of steels can be
applied, such as Al-killed steels, ultra-low carbon steel
sheets to which Ti, Nb, etc. are added, high-strength
15 steels produced by adding strengthening elements such as
P, Si, Mn, etc. to the above steels, and stainless
steels.

A method for producing a product according to the
present invention is not particularly regulated and
20 various methods such as continuous plating method for
steel sheets, hot dip plating method for steel materials
and wire rods can be applied. In the case of applying Ni
pre-plating as the lower layer, a commonly adopted pre-
plating method may be applied. A product produced
25 according to the present invention can secure a plating
layer having a good surface smoothness even when a
cooling rate is low, and therefore the effect of the
present invention is conspicuous in hot dip plating and
hot dip plating of a material having a large thickness
30 wherein a large cooling rate is hard to secure.

Though the deposition amount of plating is not
particularly regulated, a desirable amount is 10 g/m^2 or
more from the viewpoint of corrosion resistance and 350
 g/m^2 or less from the viewpoint of workability.

35 The present invention is hereunder explained
concretely on the basis of Examples.

Example 1

Cold-rolled steel sheets 2.0 mm in thickness were prepared, subjected to hot dip plating for three seconds at 400°C to 700°C in a plating bath wherein the amounts
5 of added elements were changed and to N₂ wiping for adjusting the plated amount to 140 g/m², and then cooled at a cooling rate of 10°C/sec. or lower. The compositions of the plated layers of Zn-type plated steel sheets and Al-type plated steel sheets thus produced are
10 shown in Tables 1 and 2, respectively.

Smoothness was evaluated by measuring the roughness in the wavelength range of 50 μm or more and regarding the roughness of 2 μm or less as acceptable.

The plated steel sheets thus produced were polished
15 at an inclination of 10 degrees, an intermetallic compound was searched for by SEM, and the intermetallic compound was determined from the composition rate obtained by EPMA. In the evaluation, when an Al-type intermetallic compound was confirmed in or beside an Al
20 phase, it was judged to be acceptable.

The evaluation results are shown in Tables 1 and 2. In the cases of Nos. 1, 6, 11, 16, 21, 26 and 31, an intermetallic compound was not contained in an Al phase and therefore smoothness was unacceptable. In all the
25 other cases, good smoothness was obtained.

Table 1

No.	Composition of hot dip galvanized layer (wt%)			Intermetallic compound	Lattice constant of compound (Å)			Inter-metallic compound in Al phase	Roughness evaluation	Remarks
	Al	Mg	Si		a	b	c			
1	5			-				Unaccept.	Unaccept.	Comparable
2	5			TiAl ₃	3.8537		8.5839	Accept.	Accept.	Invented
3	5			NiAl ₃	6.598	7.352	4.802	Accept.	Accept.	Invented
4	5			ZrAl ₃	4.009		17.281	Accept.	Accept.	Invented
5	5			SrAl ₄	4.46		11.07	Accept.	Accept.	Invented
6	11	3		-				Unaccept.	Unaccept.	Comparable
7	11	3		TiAl ₃	3.8537		8.5839	Accept.	Accept.	Invented
8	11	3		NiAl ₃	6.598	7.352	4.802	Accept.	Accept.	Invented
9	11	3		ZrAl ₃	4.009		17.281	Accept.	Accept.	Invented
10	11	3		SrAl ₄	4.46		11.07	Accept.	Accept.	Invented
11	11	3	0.05	-				Unaccept.	Unaccept.	Comparable
12	11	3	0.05	Ti(Al _{0.85} Si _{0.15}) ₃	3.78		8.538	Accept.	Accept.	Invented
13	11	3	0.05	NiAl ₃	6.598	7.352	4.802	Accept.	Accept.	Invented
14	11	3	0.05	ZrAl ₃	4.009		17.281	Accept.	Accept.	Invented
15	11	3	0.05	SrAl ₄	4.46		11.07	Accept.	Accept.	Invented
16	55		1.5	-				Unaccept.	Unaccept.	Comparable
17	55		1.5	Ti(Al _{0.85} Si _{0.15}) ₃	3.78		8.538	Accept.	Accept.	Invented
18	55		1.5	NiAl ₃	6.598	7.352	4.802	Accept.	Accept.	Invented
19	55		1.5	ZrAl ₃	4.009		17.281	Accept.	Accept.	Invented
20	55		1.5	SrAl ₄	4.46		11.07	Accept.	Accept.	Invented
21	55	3	1.5	-				Unaccept.	Unaccept.	Comparable
22	55	3	1.5	Ti(Al _{0.85} Si _{0.15}) ₃	3.78		8.538	Accept.	Accept.	Invented
23	55	3	1.5	NiAl ₃	6.598	7.352	4.802	Accept.	Accept.	Invented
24	55	3	1.5	ZrAl ₃	4.009		17.281	Accept.	Accept.	Invented
25	55	3	1.5	SrAl ₄	4.46		11.07	Accept.	Accept.	Invented

Table 2

No.	Composition of Al hot dip plated layer (wt%)			Intermetallic compound	Lattice constant of compound (Å)			Inter-metallic compound in Al phase	Roughness evaluation	Remarks
	Al	Mg	Si		a	b	c			
26			10	-				Unaccept.	Unaccept.	Comparable
27			10	Ti(Al _{0.85} Si _{0.15}) ₃	3.78		8.538	Accept.	Accept.	Invented
28			10	NiAl ₃	6.598	7.352	4.802	Accept.	Accept.	Invented
29			10	ZrAl ₃	4.009		17.281	Accept.	Accept.	Invented
30			10	SrAl ₄	4.46		11.07	Accept.	Accept.	Invented
31		6	10	-				Unaccept.	Unaccept.	Comparable
32		6	10	Ti(Al _{0.85} Si _{0.15}) ₃	3.78		8.538	Accept.	Accept.	Invented
33		6	10	NiAl ₃	6.598	7.352	4.802	Accept.	Accept.	Invented
34		6	10	ZrAl ₃	4.009		17.281	Accept.	Accept.	Invented
35		6	10	SrAl ₄	4.46		11.07	Accept.	Accept.	Invented

5 Example 2

Cold-rolled steel sheets 2.0 mm in thickness were prepared, subjected to hot dip plating for three seconds at 400°C to 600°C in a Zn alloy plating bath wherein the amounts of added elements were changed and to N₂ wiping for adjusting the plated amount to 140 g/m², and then cooled at a cooling rate of 10°C/sec. or lower. The compositions of the plated layers of the plated steel sheets thus produced are shown in Table 3.

Smoothness was evaluated by measuring the roughness in the wavelength range of 50 μm or more and regarding the roughness of 2 μm or less as acceptable.

The evaluation results are shown in Table 3. In the cases of Nos. 1 and 23, an intermetallic compound was not contained in the plated layers and, therefore, the smoothness was unacceptable. In all the other cases, good smoothness was obtained.

Table 3

No.	Composition of hot dip galvanized layer (mass%)				Intermetallic compound	Roughness evaluation	Remarks
	Mg	Al	Si	Intermetallic compound			
1	3	11			-	Unaccept.	Comparable
2	3	11		0.1	TiAl ₃	Accept.	Invented
3	3	11		0.1	NiAl ₃	Accept.	Invented
4	3	11		0.1	Co ₂ Al ₉	Accept.	Invented
5	3	11		0.1	CrAl ₇	Accept.	Invented
6	3	11		0.1	MnAl ₆	Accept.	Invented
7	3	11		0.1	CeZn ₂ Al ₂	Accept.	Invented
8	3	11		0.1	Al ₉ Ir ₂	Accept.	Invented
9	3	11		0.1	Al ₁₁ La ₃	Accept.	Invented
10	3	11		0.1	Al ₁₂ Mo	Accept.	Invented
11	3	11		0.1	NbAl ₃	Accept.	Invented
12	3	11		0.1	Al ₂ Se ₃	Accept.	Invented
13	3	11		0.1	TaAl ₃	Accept.	Invented
14	3	11		0.1	Zr ₂ ZnAl ₃	Accept.	Invented
15	3	11		0.1	Al ₂ Ca	Accept.	Invented
16	3	11		0.1	Ti ₇ Al ₅ Si ₁₂	Accept.	Invented
17	3	11		0.1	FeNiAl ₉	Accept.	Invented
18	3	11		0.1	Fe ₃ NiAl ₁₀	Accept.	Invented
19	3	11		0.1	TiAl ₂	Accept.	Invented
20	3	11		0.1	TiAl	Accept.	Invented
21	3	11		0.1	Ni ₂ Al ₃	Accept.	Invented
22	3	11		0.1	NiAl	Accept.	Invented
23	3	11	0.05		-	Unaccept.	Comparable
24	3	11	0.05	0.1	TiAl ₃	Accept.	Invented
25	3	11	0.05	0.1	NiAl ₃	Accept.	Invented
26	3	11	0.05	0.1	Co ₂ Al ₉	Accept.	Invented
27	3	11	0.05	0.1	CrAl ₇	Accept.	Invented
28	3	11	0.05	0.1	MnAl ₆	Accept.	Invented
29	3	11	0.05	0.1	CeZn ₂ Al ₂	Accept.	Invented
30	3	11	0.05	0.1	Al ₉ Ir ₂	Accept.	Invented
31	3	11	0.05	0.1	Al ₁₁ La ₃	Accept.	Invented
32	3	11	0.05	0.1	Al ₁₂ Mo	Accept.	Invented
33	3	11	0.05	0.1	NbAl ₃	Accept.	Invented
34	3	11	0.05	0.1	Al ₂ Se ₃	Accept.	Invented
35	3	11	0.05	0.1	TaAl ₃	Accept.	Invented
36	3	11	0.05	0.1	Zr ₂ ZnAl ₃	Accept.	Invented
37	3	11	0.05	0.1	Al ₂ Ca	Accept.	Invented
38	3	11	0.05	0.1	Ti ₇ Al ₅ Si ₁₂	Accept.	Invented
39	3	11	0.05	0.1	FeNiAl ₉	Accept.	Invented
40	3	11	0.05	0.1	Fe ₃ NiAl ₁₀	Accept.	Invented
41	3	11	0.05	0.1	TiAl ₂	Accept.	Invented
42	3	11	0.05	0.1	TiAl	Accept.	Invented
43	3	11	0.05	0.1	Ni ₂ Al ₃	Accept.	Invented
44	3	11	0.05	0.1	NiAl	Accept.	Invented

Industrial Applicability

5 The present invention makes it possible to produce a plated steel sheet excellent in surface smoothness without the formation of ruggedness on the surface even when a solidification speed of plating is low and to provide a very excellent effect industrially.